Mixed effects of climate variation on the scots pine forests: Age and species mixture matter

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ABSTRACT

Understanding and unravelling the direct and indirect effects of ongoing and predicted climate change on the vitality and productivity of Scots pine forests is particularly important for Romania and other parts of eastern Europe, where the species represents an essential ecological and economic value. Here, we introduce the first nation-wide network of 34 Scots pine chronologies of basal area increment (BAI), and assess the species' vulnerability to climate change. Temperatures of the previous autumn, as well as current year spring and summer warmth are found to be most critical for the productivity of Romania's Scots pine forests. Negative growth anomalies after hot and dry August conditions are most severe in young (< 50 years) Scots pine monocultures (> 70% dominance) at lower elevations (< 1000 m a.s.l.) across western Romania. Our findings emphasise the relevance and timeliness of carefully adapting sylvicultural management strategies to enhance the ecological and economic resilience of Romania's widespread forest areas under a warmer and drier future climate.

1. Introduction

Together with complex changes in the hydrological cycle, European temperatures have risen by approximately 0.8 °C during the 20th century, and climate models predict a continuation of this trend (IPCC, 2013). Model simulations also suggest increasing winter and decreasing summer precipitation totals for a large part of eastern Europe, including Romania (IPCC, 2013), which will result in overall drier vegetation periods and subsequent effects on the functioning and productivity of forest ecosystems (Hanewinkel et al., 2013).

Scots pine (*Pinus sylvestris* L.), the most widespread conifer species in Europe (Houston Durrant et al., 2016), receives particular attention in terms of biodiversity, conservation and economics (Matías and Jump, 2012). European Scots pine forests cover approximately 28 million hectares between the sea level and 2600 m a.s.l. at its northern and southern distribution ranges (Houston Durrant et al., 2016), respectively. It is a pioneer species with a strong competitive ability on nutrient-deficient soils (Feurdean et al., 2011). In contrast, the species performs poorly on nutrient-rich soils and it is often outcompeted by shade-tolerant late successional species. Despite its broad adaptability, the species was found to be relatively sensitive to limited water availability (Allen et al., 2010). Many tree ring-based studies from Europe reported declining growth rates of Scots pine forests after severe drought events (Bigler et al., 2006; Weber et al., 2007; Rigling et al., 2013; Pichler and Oberhuber, 2007; Martinez-Vilalta and Pinol, 2002; Sánchez-Salguero et al., 2012; Herrero et al., 2013; Dimitrov et al., 2011; Panayotov et al., 2013; Feliksik and Wilczyński, 2000 Fernández-de-Uña et al., 2013; Liang et al., 2013), often followed by insect and pathogen outbreaks (Dobbertin et al., 2007).

Despite receiving great economic and ecological importance in Romania (Lindenmayer et al., 2000; Constandache et al., 2017), Scots pine is one of the species most exposed to the impacts of climate change (Chira and Dănescu, 2013; Gill et al., 2013). In some forest areas in Romania, the Scots pine populations are vulnerable to summer drought which will likely cause the species to suffer from warming summer conditions under predicted future climate change. However, a broad-scale investigation of the species' growth-climate responses in eastern part of Europe does not exist.

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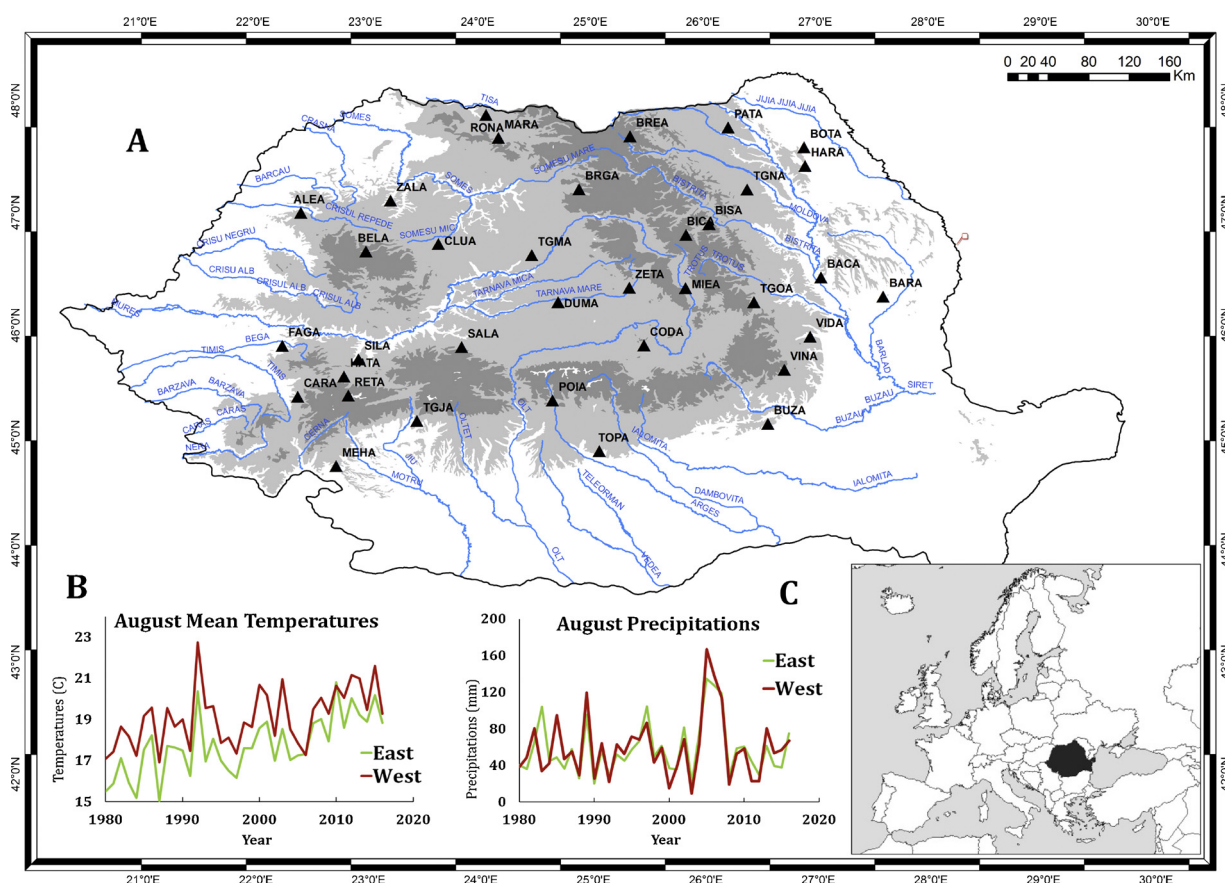 *E-mail address:* cristi.sidor@yahoo.com (C.G. Sidor).

Fig. 1. A-Locations of the 34 Scots pine tree-ring chronologies in Romania (location codes are available on Table 1); B- Regional mean August temperatures; C-Regional total August precipitations.

In this study, we introduce a new tree-ring network of 34 Scots pine sites in Romania to (i) assess the effect of climate variation on the radial growth, and (ii) to identify the most drought-prone pine forests in the country. We perform state-of-the-art analyses to quantify the vulnerability and adaptability of Romania's pine stands under warmer and drier summers and use this information to refine forest management strategies for the future.

2. Materials and methods

We selected a total of 34 sampling sites in either pure or mixture Scots pine (*Pinus sylvestris*) forest stands that are rather equally distributed across Romania (Fig. 1). The elevation of the sample plots ranged from 100 to 1600 m a.s.l. The resulting network represents the first nationwide network of > 1400 individual tree-ring series.

At each sampling site, we collected core samples 5 mm in diameter at 1.30 m stem height from > 40 dominant pines (Table 1). One core per tree (Bosela et al., 2014) was sampled in the autumn 2015 and during the vegetation season in 2016. We prepared all cores according to standard dendrochronological procedures, including drying, mounting and sanding (Cook et al., 1990). We then measured tree-ring widths on scanned images at a high resolution (1200 dpi) using the Coorecorder software (Cybis Elektronik, 2016). All individual ring-width series were visually and statistically checked for measurement errors. The samples were cross-dated in TSAP-Win software (RINNT-ECH, Inc.), in which the individual series were graphically compared with an average chronology and the reliability of cross dating was verified in COFECHA software (Holmes, 1983). The basal area increment (BAI), a more representative characteristic of the tree biomass and stand productivity (Motta and Nola, 2001), was computed for each series, assuming circular stem shape at sampling height (Monserud and

Sterba, 1996). Since BAI series still preserves a size-related trend (Biondi and Qeadan, 2008), we further applied cubic smoothing spline with 50% frequency response cut-off at 67% of the individual series lengths to each series. We computed the BAI indices (BAIi) as ratios between the observed and fitted BAI, and the residual autocorrelation was removed using an autoregressive model (Cook, 1987). Site-specific BAIi chronologies were calculated using bi-weight robust mean. All these analyses were done using the "dplR" (Bunn et al., 2017) and "treeclim" (Zang and Biondi, 2015) packages in R (R Core Team, 2017).

We calculated various statistics, frequently used in dendrochronology (Fritts, 1976), for each site BAI chronology (Table 1). The mean sensitivity (MS) is an indicator of the mean relative change between consecutive ring widths and is calculated as the absolute difference between consecutive indices divided by their mean value. The mean RBAR is a measure of the variance between the single series in a chronology and the series inter-correlation (SI)is a measure of the strength of the signal (typically the climate signal) common to all sampled trees at the site (Cook et al., 1990). Moreover, the mean correlation coefficient between the individual and the mean series was computed to assess the quality of the BAI chronologies.

In the next step, we clustered the sample sites into age and species-mixture categories. We classified the sites into younger than and older than 50 years because the growth in total volume production of Scots pine usually culminates approximately at this growth stage. Regarding the species mixture, we used a threshold of 70% of pine proportion to classify the sample sites into pure pine or mixed forests.

Monthly precipitation totals and temperature means over the period 1984–2015 were extracted for each site from the gridded, high-resolution E-OBS dataset (Haylock et al., 2008). We calculated Pearson's correlation coefficients between BAI chronologies and climate variables to assess the effect of climate variation on the pine radial growth. We

Table 1
Geographic characteristics and statistic parameters of Scots pine tree ring chronologies.

Site name	Site code	Elevation (m a.s.l.)	Latitude	Longitude	Chronology cover	Chronology lenght	Composition	No. of trees sampled	Mean ring width(mm)	Mean sensitivity	Mean Rbar	Correlation with Master
Aleşd - Bihor	ALEA	500	47.0011	22.3978	1975-2016	40	Over 70% P. s.	40	2.8	0.298	0.480	0.680
Bacău - Bacău	BACA	350	46.4225	27.02	1979-2016	37	Over 70% P. s.	40	3.6	0.249	0.401	0.591
Bârlad - Vaslui	BARA	100	46.2561	27.5727	1979-2016	37	Over 70% P. s.	40	3.6	0.25	0.410	0.602
Cluj - Cluj	CLUA	600	46.7238	23.6197	1982-2016	34	Over 70% P. s.	43	3.1	0.233	0.421	0.644
Maramureş - Maramureş	MARA	850	47.6669	24.1522	1905-2015	41	Over 70% P. s.	41	1.6	0.271	0.391	0.593
Topolniţa - Mehedinţi	MEHA	500	44.7449	22.7091	1969-2015	46	Over 70% P. s.	40	2.6	0.316	0.317	0.591
Rona - Maramureş	RONA	450	47.8846	24.0323	1979-2015	36	Mixture stands	40	3.0	0.236	0.355	0.624
Sălişte - Sibiu	SALA	650	45.8055	23.8258	1902-2016	114	Over 70% P. s.	42	1.5	0.302	0.469	0.651
Zetea - Harghita	ZETA	700	46.3342	25.3153	1936-2016	80	Over 70% P. s.	40	2.4	0.271	0.435	0.608
Beliş - Cluj	BELA	1100	46.6561	22.9731	1961-2016	55	Mixture stands	41	2.5	0.242	0.342	0.599
Bicaz chei - Neamţ	BICA	1000	46.8061	25.8227	1939-2016	83	Mixture stands	40	1.5	0.278	0.284	0.561
Bicaz sat - Neamţ	BISA	600	46.9015	26.0246	1958-2016	58	Over 70% P. s.	40	1.8	0.29	0.513	0.783
Botoşani - Botoşani	BOTA	200	47.5832	26.8696	1978-2016	38	Mixture stands	42	3.7	0.285	0.485	0.640
Codlea - Braşov	CODA	600	45.8198	25.4462	1946-2016	70	Over 70% P. s.	40	2.6	0.28	0.351	0.641
Dumitreşti - Sibiu	DUMA	420	46.2057	24.6829	1906-2016	110	Over 70% P. s.	45	1.7	0.292	0.328	0.609
Făget - Timişoara	FAGA	200	45.8069	22.2241	1975-2015	40	Over 70% P. s.	40	3.3	0.245	0.402	0.652
Haţeg - Hunedoara	HATA	550	45.5428	22.7797	1984-2016	32	Over 70% P. s.	40	2.9	0.314	0.444	0.689
Miercurea Ciuc - Harghita	MIEA	500	46.3312	25.8161	1898-2016	118	Mixture stands	40	1.1	0.329	0.397	0.651
Poiana Cerbului - Argeş	POIA	900	45.3305	24.6338	1968-2015	47	Over 70% P. s.	40	2.7	0.246	0.399	0.639
Silvaşu - Hunedoara	SILA	350	45.6972	22.9008	1978-2016	38	Over 70% P. s.	44	3.2	0.318	0.475	0.610
Târgu Jiu - Gorj	TGJA	380	45.1479	23.4291	1972-2015	43	Mixture stands	40	2.6	0.325	0.478	0.676
Târgu Mureş - Mureş	TGMA	500	46.6253	24.4494	1975-2016	41	Mixture stands	40	2.4	0.315	0.450	0.498
Târgu Neamţ - Neamţ	TGNA	500	47.2094	26.3624	1922-2016	94	Mixture stands	40	1.0	0.35	0.296	0.604
Târgu Ocna - Bacău	TGOA	600	46.2063	26.4248	1870-2015	145	Over 70% P. s.	41	1.2	0.266	0.458	0.630
Topoloveni - Argeş	TOPA	350	44.8787	25.0498	1972-2015	43	Mixture stands	40	2.8	0.315	0.553	0.690
Vidra - Vrancea	VIDA	350	45.8924	26.9178	1966-2016	50	Mixture stands	41	1.9	0.287	0.299	0.557
Zalău - Sălaj	ZALA	300	47.1081	23.1939	1904-2016	112	Mixture stands	40	1.3	0.306	0.414	0.511
Breaza - Suceava	BREA	1300	47.6800	25.3178	1820-2016	194	Mixture stands	40	1.1	0.231	0.279	0.598
Mureşenii Bârgăului - Bistriţa	BRGA	700	47.2101	24.8733	1920-2016	96	Over 70% P. s.	40	1.8	0.27	0.353	0.603
Buzău - Buzău	BUZA	650	45.1213	26.5482	1968-2016	48	Mixture stands	40	2.5	0.25	0.354	0.575
Caransebeş – Caraş Severin	CARA	650	45.3647	22.3696	1984–2015	31	Over 70% P. s.	40	4.2	0.238	0.350	0.585
Pătrăuţi - Suceava	PATA	400	47.7583	26.1931	1890-2016	126	Mixture stands	42	2.0	0.23	0.297	0.562
Retezat - Hunedoara	RETA	1600	45.3767	22.8122	1875-2016	141	Mixture stands	59	1.5	0.191	0.240	0.493
Vintileasca - Vrancea	VINA	800	45.6032	26.6928	1890-2016	126	Over 70% P. s.	40	2.0	0.271	0.384	0.552

used "treeclim" R package (Zang and Biondi, 2015) to calculate correlation coefficients between the BAI chronologies and the gridded climate data. A bootstrap approach in "treeclim" R package (Zang and Biondi, 2015) was used to test significance of the individual growth-climate relationships. The hydrological year starting from previous September to current August was considered most relevant for tree-ring formation.

To explore spatial pattern of the growth-climate responses, we carried out redundancy analysis (RDA). We preferred RDA over other multivariate methods because it explicitly models response variables as a function of explanatory variables (Legendre and Legendre, 1998). In RDA, we used matrix of correlations between site BAI chronologies and monthly climate variables as response variable and stand age, Scots pine's proportion and elevation above sea level as explanatory variables. We selected a common period of 1984–2015 to calculate the growth-climate correlations in all sites. We drew biplot from RDA results to display dissimilarities in the climate responses between the site chronologies as well as the effect of the explanatory variables. In RDA, the ordination axes are constrained to be linear combinations of explanatory variables. Those vectors that are pointing in roughly the same direction indicate a high positive correlation, whereas the vectors pointing in opposite directions show a high negative correlation. If the vectors are organized in biplot at a right angle, it suggests no correlation among them (ter Braak and Prentice, 1988). Moreover, the variables with longer vectors are more important than those that have shorter lengths (Legendre and Legendre, 1998). We used the XLSTAT software (XLSTAT, 2017) to run RDA.

For spatial interpolation of the growth-climate responses among the 34 sites, we used an inverse distance weighting interpolation in QGIS software (QGIS Development Team, 2009).

We applied moving correlation in 20-year moving periods on mean BAI chronologies to investigate changes in the climate responses of pine populations.

3. Results

3.1. Chronology statistics

Chronology length ranged from 32 to 194 years (Table 1). The mean ring width varied between 1.0 and 3.7 mm. The mean sensitivity is relatively high for the all BAI chronologies, ranging from 0.19 to 0.33. The mean correlation coefficients among BAI series (rbar) within the site chronologies spanned between 0.24 and 0.55. Both the mean sensitivity and the mean rbar were negatively correlated with the elevation above sea level. The mean sensitivity and mean correlation coefficient among tree-ring series changed significantly along the elevation (r = 0.47, resp. r = 0.49, p < 0.05). The average of the correlations between individual series and the mean chronology was 0.612.

3.2. Growth-climate relationship

Temperature showed a stronger relationship with the radial increment than precipitation for almost all chronologies (Fig. 2). A negative correlation was found for the winter precipitation in most series, while a positive signal was observed mainly for the summer months. The effect of temperature on the radial growth of pine trees largely varied and depended on tree age and species composition of the stands. Higher winter temperature positive correlated with the BAIi in all sites, but reaching significance mainly for the mixed-species stands older than 50 years.

Higher June-September temperatures negatively affected the pine-dominated stands (with the proportion of pine over 70% from a number of trees) younger than 50 years. We did not find evidence of elevational pattern in the growth-climate relationships.

3.3. The spatial pattern of climate-growth responses

Redundancy analysis (RDA) revealed spatially clustered and forest structure-related growth-climate relationships (Fig. 3). The first two RDA axes explained together almost 50% of the total variation (F1-34.30% and F2-15.62%). We found a clear clustering of the climate responses along the first axis. Unlike the first axis, there was not find any clear separation of the sites along the gradient of the second axis.

From the climatic variables considered in the analysis, March, summer and previous autumn monthly temperatures were found to be the driving factors of the BAIi variation (Fig. 4). These climatic parameters were especially important for the trees clustered in the first and the third groups. However, the responses of the two clusters were just the opposite. The chronologies from the second group had mixed responses with these climatic variables. The current-year August temperatures had the most significant effect on the radial growth of the pine populations across Romania. The temperature of the current August had a positive impact on the radial growth of trees in the third group and a significantly negative impact on the populations in the first group. The same effect, but of less intensity, showed the temperatures of the current July and June and the previous November, October and September. The temperature of the current March was the driving factor in the second RDA axis.

Site and stand characteristics were the additional factors influencing the responses of pine trees to climate variation (Figs. 2 and 5). The forest stands aggregated in the first group were younger than 50 years, with the proportion of pine trees over 70% and were located at lower elevations (below 1000 m a.s.l.). Stands older than 50 years including both pure and mixed-species structures and located along the entire elevation gradient represented the third group. The second group included stands of all ages, both pure and mixed-species, and along the entire altitudinal gradient.

Spatial interpolation of the correlations between the BAIi chronologies and the current August temperature split the Romanian territory into two parts (Fig. 6). The pine populations in the western part of Romania had significantly negative responses, whereas the trees in the eastern part were positively reacting to the current year August temperature, irrespective of the elevation zone. The general trend of the regional mean August temperature is similar for western and eastern part of Romania, but the absolute values are frequently higher than 1,5 °C in the west than in the east (Fig. 1B). No spatial pattern in BAIi responses were observed for the total August precipitations (Fig. 1C).

The two chronologies, representing east and west populations in Romania, showed a strong change of their climate responses to August temperature and precipitation (Fig. 7). However, while the responses did not reach significance for the east populations, the west populations became strongly sensitive since 1990s.

4. Discussions

4.1. Growth-climate relationships along ecological gradients

The wide distribution of Scots pine implies different environmental factors to drive the species' growth across latitudinal and longitudinal gradients (Matías and Jump, 2012; Matías et al., 2017). Moreover, change of climatic conditions along an elevational gradient within a region brings another variability in the species responses (Candel-Pérez et al., 2012; Matías et al., 2017). However, the present distribution of the species continues to change (Matías and Jump, 2012) due to changes in climate and land use over the past century that have been recorded (IPCC, 2013). *P. sylvestris* has recently experienced a drought stress-related decline in several parts of Europe (Bigler et al., 2006; Thabeet et al., 2009; Vacchiano et al., 2012). Moreover, the ecological theory predicts shifts in tree species distributions driven by climate warming (Lenoir et al., 2008). A recent study showed that the frequency of *P. sylvestris* decreased at higher elevations, but slightly
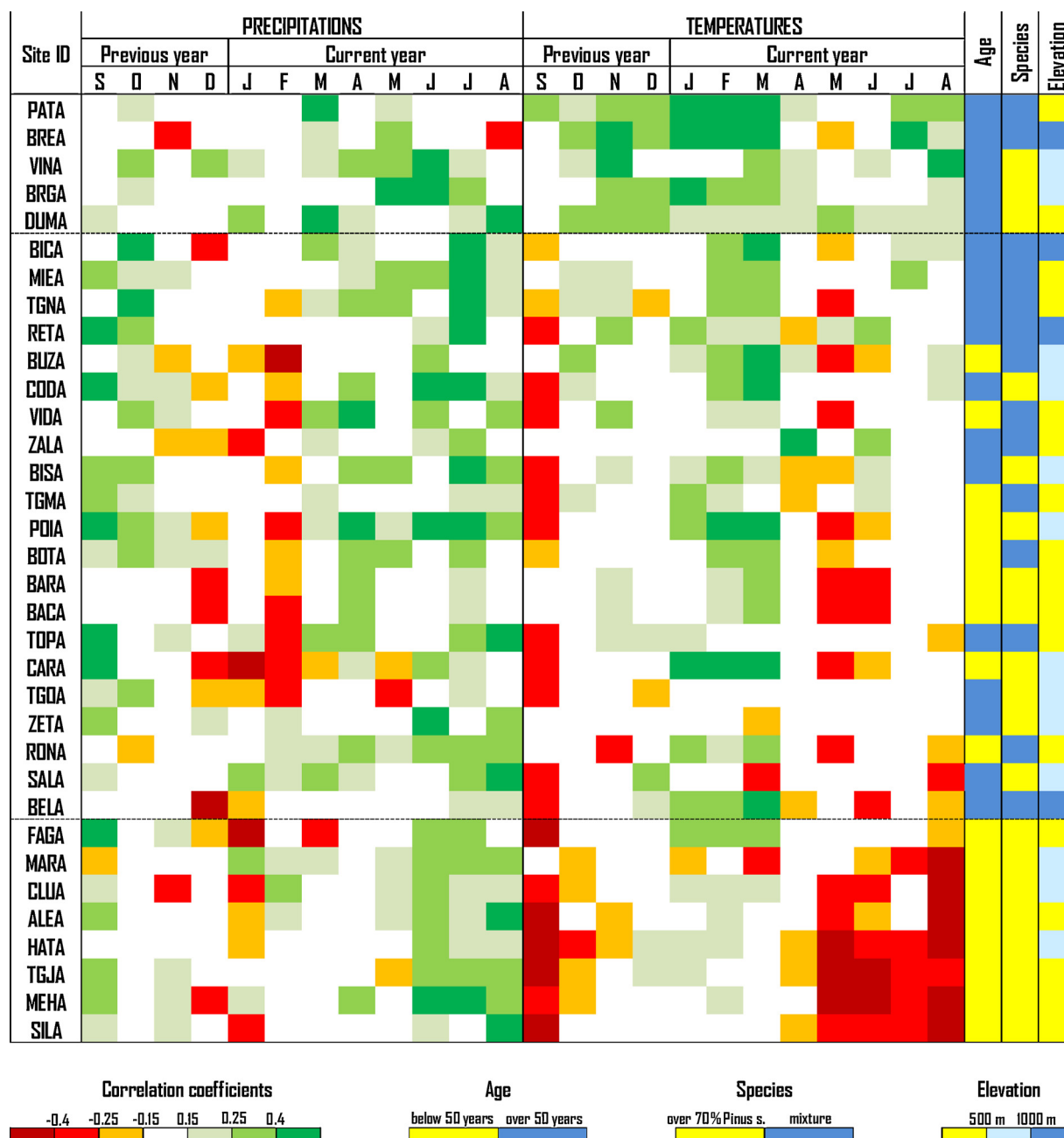
Fig. 2. Bootstrapped correlation coefficients between BAI residual chronologies and mean monthly temperatures and monthly precipitations from the prior September to current August. The age class, the species compositions and the elevation category are assigned to each site. Significant correlations (p > 0.05) are either higher than 0.25 or lower than -0.25.

increased at the lower part of the gradient during the past decades (Rabasa et al., 2013; Máliš et al., 2016). By contrast, a few studies documented increased growth rates near the tree line (Salminen and Jalkanen, 2007; Matías et al., 2017) which indicated improved climatic conditions for the species at high elevations. However, a recent study suggested that the distribution shifts might have been the result of ontogeny, rather than climate warming (Máliš et al., 2016). Nevertheless, a recent modelling suggested that the range of Scots pine will likely contract in the future under moderate to pessimistic scenarios (Dyderski et al., 2018). The contraction will most likely result in a decline of the population in the temperate zone of Europe, including Romanian pine ecosystems (Hanewinkel et al., 2013). Our study, in addition, suggests that the longitudinal, rather than elevational gradient plays important role in the species' climate sensitivity in the Carpathian Mountains.

In Romania, the range of the species spans across the entire country, from low to high elevations above sea level (Table 1), comprising a large variability of site conditions. Therefore, we expected that pine trees would respond to climate variation differently along the ecological gradients. While the reaction of the BAIi to climate was somewhat similar along the elevation gradient, it strongly differed between the western and eastern populations. The differences in climate responses were especially pronounced since 1990s (Fig. 7), suggesting an increased drought stress related to global climate warming. Summer temperature was the main driving factor for the pine populations in Romania, which was also found for other European populations, mainly in boreal (Mäkinen et al., 2000; Matías et al., 2017) and temperate (Bogino et al., 2009; Castagneri et al., 2015; González de Andrés et al., 2017; Matías et al., 2017) zones. Although precipitation amounts do not differ across Romania, the western part is warmer than the eastern
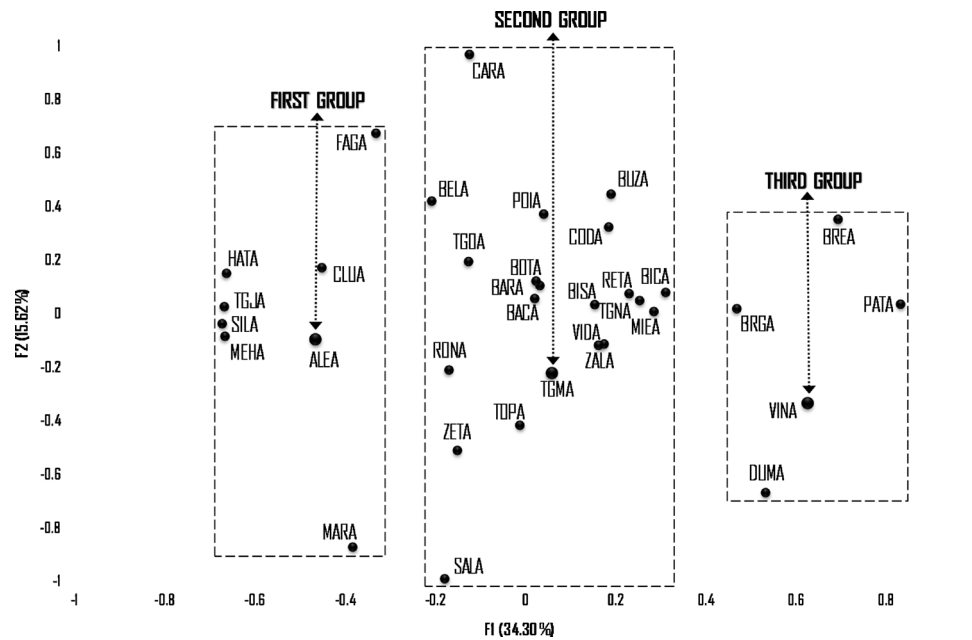
Fig. 3. RDA and Univariate clustering of F1 and F2 standardised canonical coefficients (the arrows highlight the resulted tree growth-climate responses groups).
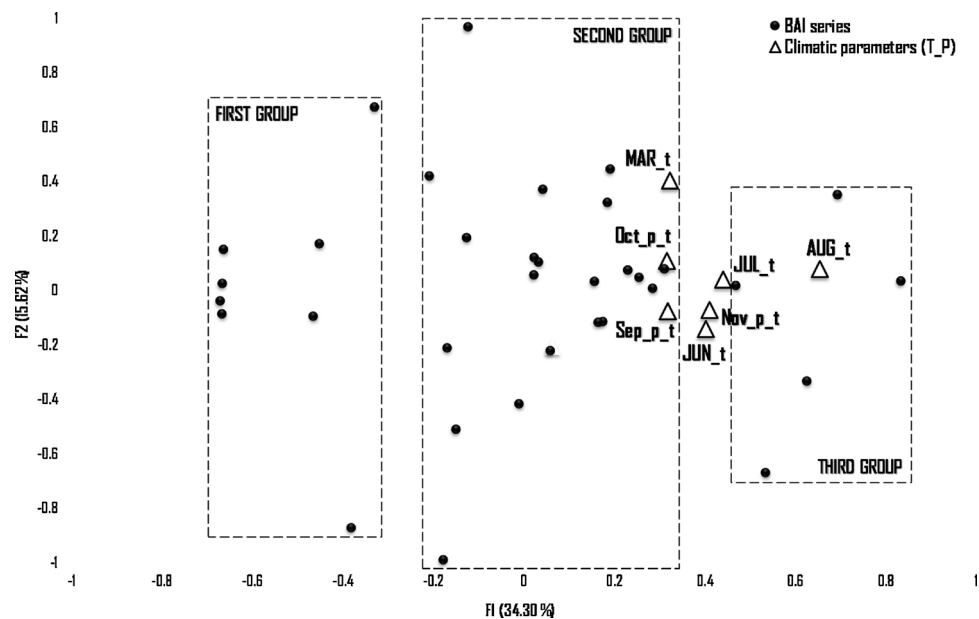

Fig. 4. RDA and Univariate clustering of F1 and F2 standardised canonical coefficients. Most influencing climate variables are shown (variability explained by axis F1 and F2: 4992%).

imposing increased drought stress on the pine ecosystems (Fig. 1). The varying water availability is thus likely the reason of the longitudinal variation in the climate responses (González de Andrés et al., 2017). Our results suggest that *P. sylvestris* in the western part of Romania, irrespective of elevation zone, will likely experience a drought-related decline under predicted future warming conditions. This growth rate decline is in contrast with the results of Matías et al., 2017, who found increased growth rates for central European pine populations and predicted that the growth would continue to increase by 2100 under scenario ECHAM A2. Such contradictions suggest that local or regional investigations should be preferred when decisions are to be made at local and regional scales.

Besides temperature, summer precipitation also have substantial positive effects on the radial growth of pine trees in Romania. However, the responses do not show such longitudinal pattern as is found for temperature. Unexpectedly, neither the precipitation-growth nor the temperature-growth relationships changed along an altitudinal gradient, which is not in line with a recently found drought-related decline of *P.sylvestris* which consequently shifted into Oak-dominated forests at lower elevations in Central Europe (Rigling et al., 2002). Less number of sites at higher elevations (> 1000 m a.s.l.) sampled for our study may, however, partly explain the no-trend revealed for elevation gradient.

Our study further revealed the effect of ageing on the climate sensitivity of *P.sylvestris*. While the influence of the temperature regime is positive for older pine trees (age > 50 yrs), the young trees express negative responses. Eco-physiological changes related to tree age causing a reduction in photosynthesis and stomatal conductance, changes in leaf structure and canopy structure may explain the age effect (Bond, 2000). The more developed root and photosynthetic
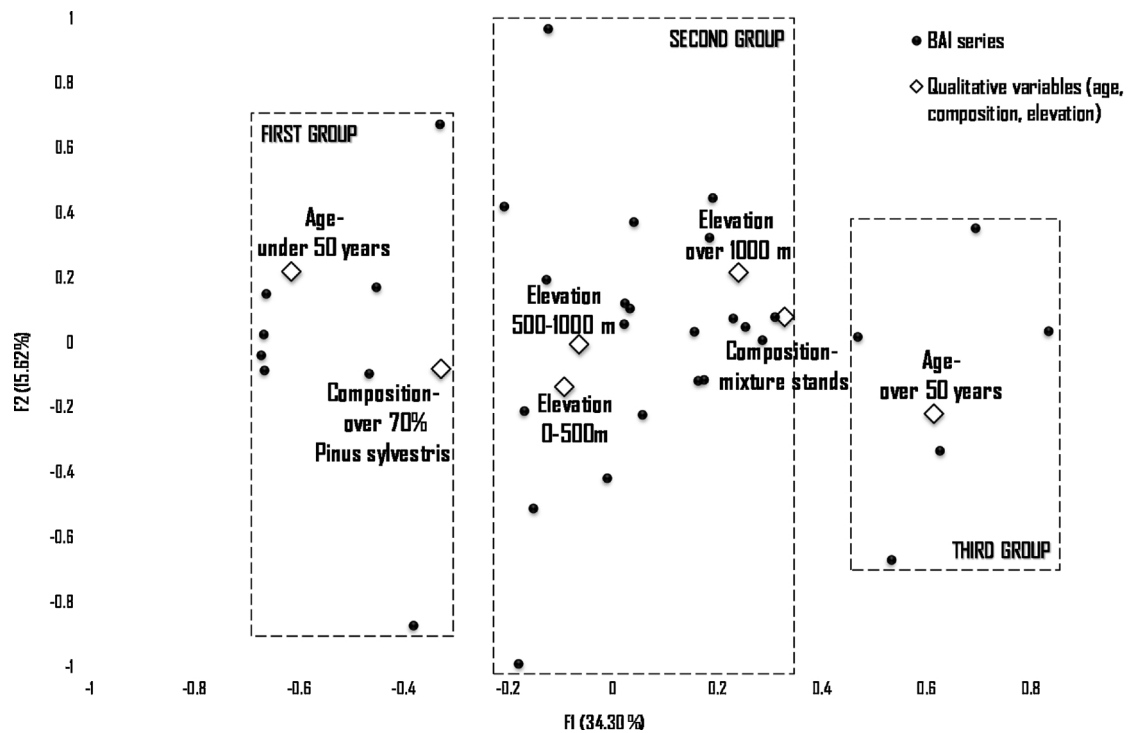
Fig. 5. RDA and Univariate clustering of F1 and F2 standardised canonical coefficients. The vector of age, species composition and elevation is shown (variability explained by axis F1 and F2: 4992%).

system of the older trees make them less vulnerable to intense and prolonged drought conditions (Colangelo et al., 2017). Moreover, the water storage in the stems increases as trees become older and provide a buffer against the short-term water stress (Anthoni et al., 2002). The reduced water-related stress of the older trees may result in a lower vulnerability to changed climatic conditions. Bogino et al. (2009) provide another support for the hypothesis of age-related change of climate sensitivity. A few studies, however, suggested a higher growth plasticity of young and a higher climate sensitivity of older beech trees (Carrer

and Urbinati, 2006; Primicia et al., 2015; Bosela et al., 2015), which contradicts the former hypothesis and call for further research to bring more light into the discussion.

4.2. Effects of species diversity on climate responses

Our study reveals that *P.sylvestris* trees are significantly less climate-sensitive when growing in mixture than that forming pure stands; thus supporting the widely accepted biodiversity-productivity hypothesis
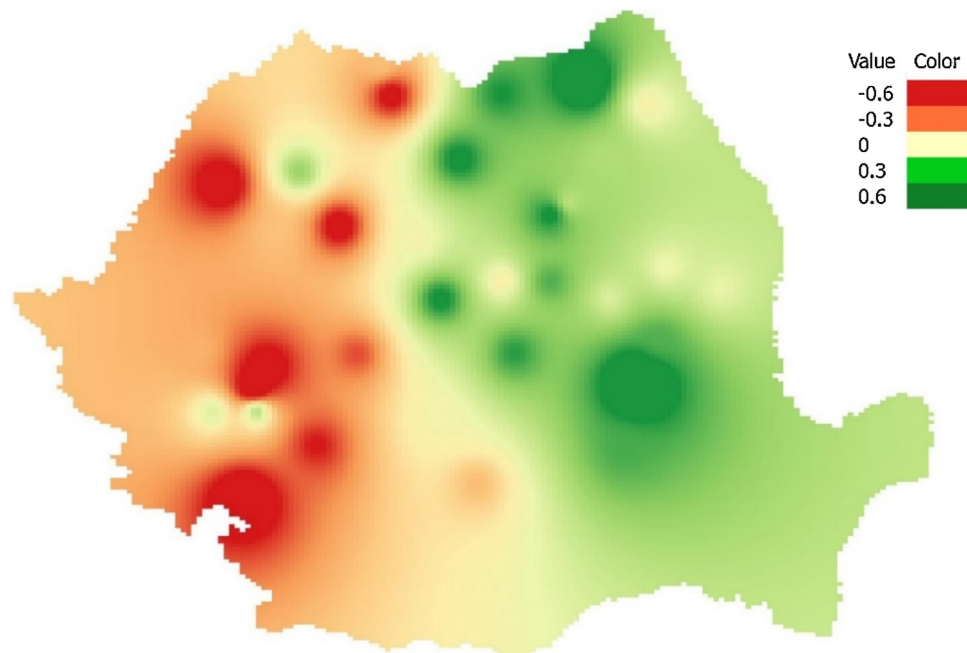

Fig. 6. Correlation of BAI chronologies with the temperatures from current August (red- minimum correlation values; green-maximum correlation values) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).
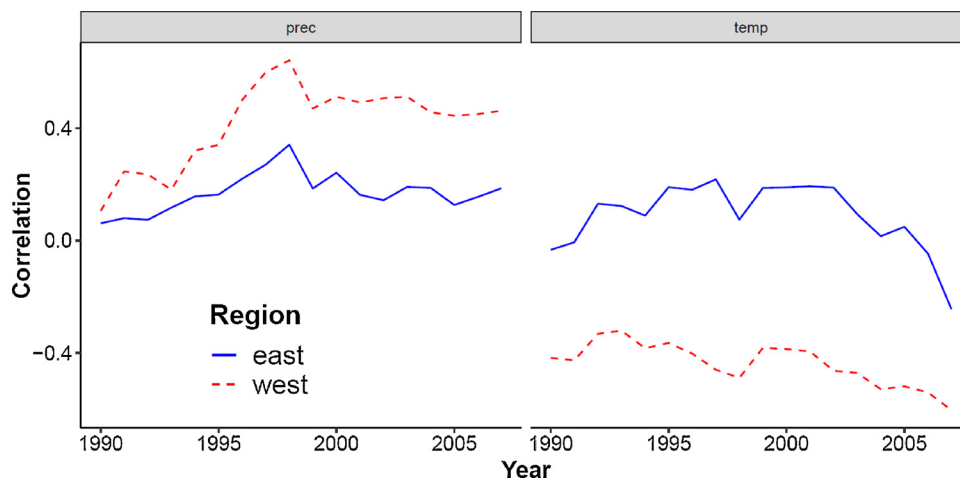
Fig. 7. 20-yr moving correlation between two regional chronologies (east and west Romania) and August mean temperature (temp) and precipitation (prec) in the period 1980 – 2017. Correlations over 0.45 become significant at 95% significance level.

(Jucker et al., 2014). This hypothesis assumes that biodiversity is a strong driver of productivity of the ecosystems across the globe (Grace et al., 2016; Duffy et al., 2017). Regarding the forest ecosystems, many studies have evidenced substantial positive effects of tree species diversity on the climate responses and productivity of some European tree species (Zhang et al., 2012; Toïgo et al., 2015). Some recent studies documented that the growth of Scots pine was reduced under increased intraspecific competition (González de Andrés et al., 2017). In diverse forests formed by species with contrasting functional traits, limited water resources can be better distributed among the neighbouring species (Farquhar et al., 1989). Interspecific differences in physiology, phenology and morphology modify water-use efficiency and thus alter the growth as compared to monospecific forests (Forrester, 2015; Forrester and Bauhus, 2016). However, a few studies suggested that species diversity might not always mitigate adverse effects of drought on forest resistance (Grossiord et al., 2014; Forrester and Bauhus, 2016). According to Grossiord et al. (2014), the higher species diversity enhances the resistance to drought in drought-prone environments, whereas the effect is strongly limited on water well-supplied sites. The different effects of species diversity on the climate sensitivity will thus require local and regional investigations to advise local forest practitioners and decision makers.

5. Conclusions

Using a unique country-scale dendroecological tree-ring network we revealed, that Scots pine populations in Romania has become highly vulnerable to ongoing climate change due to the increased intensity and frequency of drought events. Considering that all climate scenarios predict a rapid increase in temperature in the next decades, the young Scots pine monocultures at lower elevations in the western Romania will most likely reduce the timber productivity and may experience severe mortality events. Therefore, appropriate management strategies are required to ensure provisioning of ecosystem services to Romanian society in the future.

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